

# The difference asymmetries in SIDIS and the higher twists

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based on papers written with

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## The goal

to obtain the polarized parton densities

$$\Delta u \Rightarrow \Delta u_V, \quad \Delta \bar{u}$$

$$\Delta d \Rightarrow \Delta d_V, \quad \Delta \bar{d}$$

$$\Delta s, \Delta \bar{s}$$

$$\Delta G$$

We have:

DIS:       $\vec{l} + \vec{N} \rightarrow l' + X$

$$A_N^{DIS} = \frac{\Delta\sigma^{DIS}}{\sigma^{DIS}} = \frac{\sum e_q^2 (\Delta q + \Delta \bar{q})}{\sum e_q^2 (q + \bar{q})} = \frac{g_1^N}{F_1^N}$$

determine only the combinations  $(\Delta q + \Delta \bar{q})$ :

$$\Delta u + \Delta \bar{u}, \quad \Delta d + \Delta \bar{d}, \quad \Delta s + \Delta \bar{s}, \quad \Delta G.$$

## The spin of the proton

$\Delta \Sigma =$  the quark contr. to the spin of the proton:

$$\Delta \Sigma = \int dx [(\Delta u + \Delta \bar{u}) + (\Delta d + \Delta \bar{d}) + (\Delta s + \Delta \bar{s})]$$

EMC (CERN) 1989, DIS: –  $\Delta \Sigma \simeq 0.12 \sim$  too small  
‘THE SPIN CRISIS’

**expected:**  $\Delta \Sigma \simeq 1$  – in nonrelat. protons the spin is carried by the valence quarks.

assumed: SU(2) and SU(3) inv. of strong ints.

- . (Bj. and Ellis & Jaffe sum rules)  
SU(3) correct up to 20 % – does not help

Question:  $\Delta G = ?$

$$(\Delta q + \Delta \bar{q}) \Rightarrow (\Delta q + \Delta \bar{q}) - (\alpha_s/2\pi)\Delta G$$

NLO required  $\Rightarrow \Delta \Sigma$  scheme dependent

**SIDIS:**  $\overrightarrow{l} + \overrightarrow{N} \rightarrow l' + h + X, \quad h = \pi^\pm, K^\pm.$

$$A_N^h = \frac{\Delta\sigma_N^h}{\sigma_N^h} = \frac{\sum e_q^2 (\Delta q D_q^h + \Delta \bar{q} D_{\bar{q}}^h)}{\sum e_q^2 (q D_q^h + \bar{q} D_{\bar{q}}^h)}$$

HERMES & SMC

- advantage: determines  $\Delta q$  and  $\Delta \bar{q}$  separately  
 $\rightarrow D_q \neq D_{\bar{q}}$
- but: we need to know the FFs:  $D_q$  and  $D_{\bar{q}}$
- up to now  $D_q^h$  are not well known:
- $e^+e^- \rightarrow h + X \Rightarrow D_q^h + D_{\bar{q}}^h$  only  
 $\sim$  in DIS  $\Rightarrow (q + \bar{q}), (\Delta q + \Delta \bar{q})$  only
  - $l + N \rightarrow l' + h + X \Rightarrow D_q^h \& D_{\bar{q}}^h$   
 $\Rightarrow$  but low sensitivity to  $D_s^h$  etc.

EMC (1989), HERMES (2001)

- in SIDIS  $D_q^h$  and  $D_{\bar{q}}^h$  needed separately  
 $\Rightarrow$  always additional theor. assumptions about favoured and unfavoured transitions are made.
- different isospin relations about polarized sea:

$$\Delta \bar{u} = \Delta \bar{d} = \Delta \bar{s} \quad \text{or} \quad \Delta \bar{u}/\bar{u} = \Delta \bar{d}/\bar{d} = \Delta \bar{s}/\bar{s}$$

## SIDIS experiments

### done:

- 1) SMC (CERN)  $h^\pm$  on  $p$  and  $d$
- 2) HERMES (DESY)  $\pi^\pm, K^\pm$  on  $p$  and  $d$

### results:

- a) **HERMES:**  $(\Delta s + \Delta \bar{s}) \simeq 0 \Rightarrow \text{SU}(3)$  totally
- . broken E.Leader & D.Stamenov
- DIS:**  $(\Delta s + \Delta \bar{s}) < 0$
- b) **HERMES:**  $\Delta \bar{u} - \Delta \bar{d} \simeq 0$
- DIS:**  $\int dx (\bar{u} - \bar{d}) = .118 \pm .012$
- TH:** chiral models:  
 $\Delta \bar{u} - \Delta \bar{d} \neq 0$  - LO;  $(\bar{u} - \bar{d}) \neq 0$  - NLO

### coming:

- 1) COMPASS (CERN:)  
approved 1998  
taking data since 2002  $\Rightarrow \Delta G = ?$
- 2) Semi-SANE E04 113 (JLAB,USA)  
approved summer 2004  
start taking data 2006-2007  $\Rightarrow A_N^{h-\bar{h}}$

## We consider SIDIS

$$l + N \rightarrow l' + h + X, \quad \vec{l} + \vec{N} \rightarrow l' + h + X$$

What can we learn from SIDIS - pol. and unpol.  
without assuming any knowledge:

- about  $D_q^h$  and  $D_{\bar{q}}^h$
- about  $\Delta\bar{u}$ ,  $\Delta\bar{d}$ ,  $\Delta s$ ,  $\Delta\bar{s}$ ,  $\Delta G$

- We suggest to measure the difference asymmetries:

$$A_N^{h^+ - h^-} = \frac{\Delta\sigma_N^{h+} - \Delta\sigma_N^{h-}}{\sigma_N^{h+} - \sigma_N^{h-}}$$

$$R_N^{h^+ - h^-} = \frac{\sigma_N^{h+} - \sigma_N^{h-}}{\sigma_N^{DIS}}$$

## We show that one can determine directly:

- $\Delta u_V$ ,  $\Delta d_V \rightarrow$  LO and NLO – **JefLab**
- $\Delta\bar{u} - \Delta\bar{d} \rightarrow$  LO and NLO – **JefLab**
- $s(x) - \bar{s}(x)$ ,  $\Delta s(x) - \Delta\bar{s}(x) \rightarrow$  LO and NLO
- $D_u^{\pi^+ - \pi^-} \rightarrow$  LO and NLO
- possible tests of LO

to be measured in JefLab – with A-rating approved  
last summer!

## PROBLEMS

DIS & SIDIS polarized  $\Rightarrow Q^2 = \text{small}, Q^2 \geq M^2$



HERMES:  $Q^2 \simeq 1 - 10 \text{ GeV}^2$

JLab:  $Q^2 \simeq 1, 3 - 3, 5 \text{ GeV}^2$

perturb. QCD:  $Q^2 \gg M^2$  – Higher twists needed!

How HT's modify the difference asymmetries?

Thinking of possible ways out.

$$\overrightarrow{l} + \overrightarrow{N} \rightarrow l' + h + X$$

The general formula in SIDIS,  $Q^2 \gg M^2$ :

$$\begin{aligned}\Delta\tilde{\sigma}_N^h \propto \sum_q e_q^2 & \left\{ \Delta q \otimes \Delta\hat{\sigma}(\gamma q \rightarrow qX) \otimes D_q^h \right. \\ & + \Delta q \otimes \hat{\sigma}(\gamma q \rightarrow GX) \otimes D_G^h \\ & \left. + \Delta G \otimes \Delta\hat{\sigma}(\gamma G \rightarrow q\bar{q}X) \otimes (D_q^h + D_{\bar{q}}^h) \right\}\end{aligned}$$

$\Delta q(x, t)$  and  $D_q^h(z, t)$   $\Rightarrow$  from experiment

$\Delta\hat{\sigma}_{ff'}$   $\Rightarrow$  theor. calculated in perturb. QCD:

$$\Delta\hat{\sigma}_{ff'} = \Delta\hat{\sigma}_{ff'}^{(0)} + \frac{\alpha_s}{2\pi} \Delta\hat{\sigma}_{ff'}^{(1)} + \dots$$

### The difference asymmetries $A_N^{h-\bar{h}}$

C-inv. implies:  $D_G^{h-\bar{h}} = 0$ ,  $D_q^{h-\bar{h}} = -D_{\bar{q}}^{h-\bar{h}}$

$\Rightarrow$  In all orders in QCD all gluons cancel :

$$\begin{aligned}\Delta\tilde{\sigma}_N^{h-\bar{h}} \propto & [4\Delta u_V \otimes D_u^{h-\bar{h}} + \Delta d_V \otimes D_d^{h-\bar{h}} \\ & + (\Delta s - \Delta \bar{s}) \otimes D_s^{h-\bar{h}}] \otimes \Delta\hat{\sigma}(\gamma q \rightarrow qX) \\ \Delta\hat{\sigma}_{qq} = & \Delta\hat{\sigma}_{qq}^{(0)} + \frac{\alpha_s}{2\pi} \Delta\hat{\sigma}_{qq}^{(1)} + \dots\end{aligned}$$

- only NS  $\Rightarrow$  gluons do not reappear in  $Q^2$ -evol.
- sensitive to  $\Delta u_V$ ,  $\Delta d_V$  &  $(\Delta s - \Delta \bar{s})$  only

Further  $\Delta\tilde{\sigma}_N^{h-\bar{h}}$  depends on the final hadron  $h$ .

$$\overrightarrow{t} + \overrightarrow{N} \rightarrow l' + \pi^\pm + X$$

SU(2) and C:  $D_u^{\pi^+ - \pi^-} = -D_d^{\pi^+ - \pi^-}$ ,  $D_s^{\pi^+ - \pi^-} = 0$

$\Delta u_V, \Delta d_V - LO$ :

$$A_p^{\pi^+ - \pi^-}(x, z, Q^2) = \frac{4\Delta u_V - \Delta d_V}{4u_V - d_V}(x, Q^2)$$

$$A_n^{\pi^+ - \pi^-}(x, z, Q^2) = \frac{4\Delta d_V - \Delta u_V}{4d_V - u_V}(x, Q^2)$$

The FFs completely cancel!

Frankfurt et al, P.L. B (1989)

E. Ch. & E. Leader, P.L. B (1999)

$\Rightarrow$  2 algebraic eqs. for  $\Delta u_V$  and  $\Delta d_V$ :

$$\Delta u_V = \left\{ 4(4u_V - d_V)A_p^{\pi^+ - \pi^-} + (4d_V - u_V)A_n^{\pi^+ - \pi^-} \right\}$$

$$\Delta d_V = \left\{ 4(4d_V - u_V)A_n^{\pi^+ - \pi^-} + (4u_V - d_V)A_p^{\pi^+ - \pi^-} \right\}$$

$z$  = passive observable - test of LO

## NLO

**LO**   **NLO**  
 alg. eqs. (simple products)    $\Rightarrow$   int. eqs. (convolutions)

$$\begin{aligned}
 q(x, U^2) &\Rightarrow \int \frac{dx'}{x'} q\left(\frac{x}{x'}\right) C(x') = q \otimes C \\
 q(x, Q^2) D(z, Q^3) &\Rightarrow \int \frac{dx'}{x'} \int \frac{dz'}{z'} q\left(\frac{x}{x'}\right) C(x', z') D\left(\frac{z}{z'}\right) \\
 &= q \otimes C \otimes D
 \end{aligned}$$

$C$  are known Wilson coefficients.

LO:  $\Rightarrow$  no gluons in the cross section

NLO:  $\Rightarrow$  gluons in  $d\sigma$ :  $G(x)$ ,  $\Delta G(x)$ ,  $D_G^h(z)$

- polarized DIS

$$\begin{aligned}
 g_1^p(x, Q^2) &= \frac{1}{2} \sum_i e_i^2 \left[ \Delta q_i \left( 1 + \otimes \frac{\alpha_s(Q^0)}{2\pi} \delta C_q \right) + \right. \\
 &\quad \left. + \frac{\alpha_s(Q^2)}{2\pi} \Delta G \otimes \delta C_G \right]
 \end{aligned}$$

- unpolarized DIS

$$\tilde{\sigma}^{DIS}|_{LO} = 2F_1 \quad \Rightarrow \quad \tilde{\sigma}^{DIS}|_{NLO} = 2F_1 [1 + 2\gamma(y)R],$$

$$R = \frac{\sigma_L}{\sigma_T}, \quad \gamma(y) = \frac{1-y}{1+(1-y)^2}.$$

## $\Delta u_V, \Delta d_V - NLO$

E. Ch. & E. Leader, N.P. B (2001)

- From polarized SIDIS  $\Rightarrow \Delta u_V$  and  $\Delta d_V$ :

$$A_p^{\pi^+ - \pi^-} = \frac{(4\Delta u_V - \Delta d_V)[1 + \otimes(\alpha_s)\Delta C_{qq}\otimes]D_u^{\pi^+ - \pi^-}}{(4u_V - d_V)[1 + \otimes(\alpha_s)C_{qq}\otimes]D_u^{\pi^+ - \pi^-}}$$

$$A_n^{\pi^+ - \pi^-} = \frac{(4\Delta d_V - \Delta u_V)[1 + \otimes(\alpha_s)\Delta C_{qq}\otimes]D_u^{\pi^+ - \pi^-}}{(4d_V - u_V)[1 + \otimes(\alpha_s)C_{qq}\otimes]D_u^{\pi^+ - \pi^-}}$$

correct to any order in QCD:

$$\Delta C_{qq} = \Delta C_{qq}^{(1)} + \alpha_s \Delta C_{qq}^{(2)} + \dots$$

$\Rightarrow$  2 eqs. for  $\Delta u_V$  and  $\Delta d_V$

- From unpolarized SIDIS  $\Rightarrow D_u^{\pi^+ - \pi^-}(z, Q^0)$ :

$$R_p^{\pi^+ - \pi^-} = \frac{[4u_V - d_V][1 + \otimes(\alpha_s)C_{qq}\otimes]D_u^{\pi^+ - \pi^-}}{18F_1^p [1 + 2\gamma(y) R^p]}$$

$$R_n^{\pi^+ - \pi^-} = \frac{[4d_V - u_V][1 + \otimes(\alpha_s)C_{qq}\otimes]D_u^{\pi^+ - \pi^-}}{18F_1^n [1 + 2\gamma(y) R^n]}.$$

$\Rightarrow$  2 eqs. for  $D_u^{\pi^+ - \pi^-}(z, Q^2)$

$\Rightarrow \Delta u_V, \Delta d_V$  and  $D_u^{\pi^+ - \pi^-}(z, Q^2)$  are non-singlets  
and don't mix with other PDs and FFs

## Higher Twists

$$\Delta\tilde{\sigma}_p^h(x, z, Q^2) = \Delta\tilde{\sigma}_p^h(pQCD) + \Delta H_p^h(x, z, Q^2)$$

$\Delta\tilde{\sigma}_p^h(pQCD) \Rightarrow$  perturb. contr. of the individual parton  $\rightarrow$   $\log Q^2$ -dependence:  $Q^2 \gg M^2$

$\Delta H_p^h(x, z, Q^2) \Rightarrow$  HT's = correlations between the individual parton & the partons from the remnant  $\rightarrow$  power- $Q^2$  dependence;  $Q^2 \geq M^2 \Rightarrow$  non perturb.

The kinematic  $Q^2$ -terms due to target mass corrections can be included in  $\Delta\tilde{\sigma}_p^h(pQCD) \Rightarrow$  it still obeys perturb. QCD

We shall speak only about dynamical HT contributions.

## SIDIS $\pi^\pm$ + HT

Most generally:

$$R_p^{\pi^+ - \pi^-} = \frac{\tilde{\sigma}_p^{\pi^+ - \pi^-}(QCD) + H_p^{\pi^+ - \pi^-}}{\tilde{\sigma}_p^{DIS}(QCD) + H_p^{DIS}}$$

$$R_n^{\pi^+ - \pi^-} = \dots$$

$H_p^{DIS}$  and  $H_n^{DIS}$  = known, both in LO & NLO

$R_{p,n}^{\pi^+ - \pi^-} \Rightarrow \tilde{\sigma}_{p,n}^{\pi^+ - \pi^-}(QCD) + H_{p,n}^{\pi^+ - \pi^-}$  : LO & NLO

The polarized SIDIS:

$$A_p^{\pi^+ - \pi^-} = \frac{\Delta \tilde{\sigma}_p^{\pi^+ - \pi^-}(QCD) + \Delta H_p^{\pi^+ - \pi^-}}{\tilde{\sigma}_p^{\pi^+ - \pi^-}(QCD) + H_p^{\pi^+ - \pi^-}}$$

$$A_n^{\pi^+ - \pi^-} = \dots$$

The numerators are known from  $R_{p,n}^{\pi^+ - \pi^-}$

$\Rightarrow$  2 measurements:  $A_{p,n}^{\pi^+ - \pi^-}$

$\Rightarrow$  5 unknowns:  $\Delta u_V$ ,  $\Delta d_V$ ,  $D_u^{\pi^+ - \pi^-}$ ,  $\Delta H_p^{\pi^+ - \pi^-}$  &  
 $\Delta H_n^{\pi^+ - \pi^-}$

Question: Do we need power- $Q^2$  terms?

## A possible way out: relate $\Delta H_{p,n}^{\pi^+ - \pi^-}$ to $\Delta H_{p,n}^{DIS}$

- If factorization for  $\Delta \tilde{\sigma}_p^h$  when HT's:  
 $\Rightarrow$  C-inv. eliminates the GGG corrls. in  $\Delta H_p^{h-\bar{h}}$   
 $\Delta \tilde{\sigma}_p^{h-\bar{h}}(QCD)$   
 $\Rightarrow$  in  $\Delta H_p^{\pi^+ - \pi^-} \Rightarrow$  no  $\bar{q}G\bar{q}$  and  $GGG$  corrls.  
 $\Rightarrow$  only  $u_V$  &  $d_V$  correls. with the remnant

- if these corrls. are those that enter DIS:

$$\Delta H_{p,n}^h(x, z) \propto \sum e_q^2 \Delta h_{p,n}^{DIS}(q) D_q^h(z)$$

analogous to  $\Delta \sigma_{p,n}^h(x, z) \propto \sum e_q^2 \Delta q D_q^h(z)$

Recall:

$$\begin{aligned} g_1^p &= g_1^p(pQCD) + \Delta H_p^{DIS} \\ g_1^n &= g_1^n(pQCD) + \Delta H_n^{DIS} \end{aligned}$$

where we define  $\Delta h_p^{DIS}(q)$  ( $\Delta s \simeq 0$ ):

$$\begin{aligned} \Delta H_p^{DIS} &= 4\Delta h_p^{DIS}(u) + \Delta h_p^{DIS}(d) \\ \Delta H_n^{DIS} &= 4\Delta h_p^{DIS}(d) + \Delta h_p^{DIS}(u) \end{aligned}$$

$\Delta H_{p,n}^{DIS}$  = known,     *Leader, Sidorov, Stamenov (2004)*

**about  $\Delta H_{p,n}^{\pi^+ - \pi^-}$**

$$\Delta H_p^{\pi^+ - \pi^-}(x, z) \propto [4\Delta h_p^{DIS}(u) - \Delta h_p^{DIS}(d)] D_u^{\pi^+ - \pi^-}(z)$$

$$\Delta H_n^{\pi^+ - \pi^-}(x, z) \propto [4\Delta h_p^{DIS}(d) - \Delta h_p^{DIS}(u)] D_u^{\pi^+ - \pi^-}(z)$$

$\Rightarrow A_p^{\pi^+ - \pi^-}$  &  $A_n^{\pi^+ - \pi^-}$  work as before

**In general**

$$\Delta \sigma_p^h \propto \Delta q D_q^h + \Delta H_q D_q^h + \Delta q H_D^h$$

$$\Delta q \rightarrow \Delta q + \Delta H_q$$

$$D_q \rightarrow D_q + H_D^h$$

Three factorizing pieces:

**if** we ignore  $H_D \Rightarrow$  no HTs in FFs

we try to describe  $\Delta \sigma_N^h$  through  $\Delta \sigma^{DIS}$ .

Back to  $R_{p,n}^{\pi^+ - \pi^-}$



$$D_u^{\pi^+ - \pi^-} = ?$$

If analogously relate  $H_{p,n}^{\pi^+ - \pi^-}$  to the known  $H_{p,n}^{DIS}$   
under the same assumptions

NLO  $\Rightarrow R_N^{\pi^+ - \pi^-}$  will determine  $D_u^{\pi^+ - \pi^-}$  as before:

$$R_p^{\pi^+ - \pi^-} = \frac{(4u_V - d_V)[1 + (\alpha_s)C_{qq}]D_u^{\pi^+ - \pi^-} + H_p^{\pi^+ - \pi^-}}{\tilde{\sigma}_p^{DIS}(QCD) + H_p^{DIS}}$$

$$R_n^{\pi^+ - \pi^-} = \dots$$

$$H_p^{\pi^+ - \pi^-} = [4h_p^{DIS}(u) - h_p^{DIS}(d)] D_u^{\pi^+ - \pi^-}(z)$$

$$H_n^{\pi^+ - \pi^-} = [4h_p^{DIS}(d) - h_p^{DIS}(u)] D_u^{\pi^+ - \pi^-}(z)$$

$H_{p,n}^{DIS}$  = known, *Krivokhijine, Kotikov (2001)*

$$H_p^{DIS} = 4h_p^{DIS}(u) + h_p^{DIS}(d)$$

$$H_n^{DIS} = 4h_p^{DIS}(d) + h_p^{DIS}(u)$$

If factorization for  $\Delta H^{\pi^+ - \pi^-} \Rightarrow$  no FFs in LO:

$$\begin{aligned} \Delta A_p^{\pi^+ - \pi^-}(x, \underline{z}, Q^2) &= \\ &= \frac{(4\Delta u_V - \Delta d_V) + \Delta h_p/Q^2}{(4u_V - d_V) + h_p/Q^2}(x, Q^2) \end{aligned}$$

$$\Delta A_n^{\pi^+ - \pi^-}(x, \underline{z}, Q^2) = \dots$$

$z$  = passive observable

SU(2) for the polarized sea :  $(\Delta\bar{u} - \Delta\bar{d})$

We have in any order in QCD:

$$(\Delta\bar{u} - \Delta\bar{d}) = \Delta q_3 + \Delta d_V - \Delta u_V$$

where

$$\Delta q_3(x, Q^2) = (\Delta u + \Delta\bar{u}) - (\Delta d + \Delta\bar{d}).$$

Here  $\Delta q_3$  is obtained directly from DIS:

$LO$ :

$$g_1^p(x, Q^2) - g_1^n(x, Q^2) = \frac{1}{6}\Delta q_3$$

$NLO$ :

$$g_1^p(x, Q^2) - g_1^n(x, Q^2) = \frac{1}{6}\Delta q_3 \otimes \left(1 + \frac{\alpha_s(Q^2)}{2\pi}\delta C_q\right)$$

not through  $(\Delta u + \Delta\bar{u})$  &  $(\Delta d + \Delta\bar{d})$  that depend on  $\Delta s$  &  $\Delta G$ .

$\Rightarrow$  no influence from  $\Delta s$  and  $\Delta G$ .

$(\Delta\bar{u} - \Delta\bar{d}) \simeq small \mapsto NLO$  needed

## SIDIS – $\pi^\pm$

$\Delta u_V$ ,  $\Delta d_V$  and  $\Delta \bar{u} - \Delta \bar{d}$  determined in LO and NLO:

- no assumptions about FFs
- no assumptions about polarized sea densities, even  $s \neq \bar{s}$  and  $\Delta s \neq \Delta \bar{s} \Leftarrow D_s^{\pi^+ - \pi^-} = 0$
- only SU(2) and  $C$  inv. of strong ints. assumed
- only unpolarized  $u_V$  and  $d_V$  to be known
- SU(2) breaking of the sea without knowledge of  $\Delta \bar{u}$  and  $\Delta \bar{d}$
- test for LO  $\Rightarrow z = \text{passive observable}$   
If a small dependence on  $z \Rightarrow$  it can be considered as a system. th. error in LO analysis
- $\Delta q_3$ ,  $\Delta d_V$  and  $\Delta u_V$  well determined in LO however their linear combination very small – NLO corrections important in  $\Delta \bar{u} - \Delta \bar{d}$
- HTs: if  $\Delta H^{\pi^+ - \pi^-} \rightarrow \Delta H^{DIS}$

## SIDIS – $K^\pm$

$\Rightarrow$  SU(2) does not relate  $D^{K^\pm} \Rightarrow$  assumptions needed:

1.  $D_d^{K^+ - K^-} = 0$  – unfav. trans. are equal (but not small)
2.  $\Delta s - \Delta \bar{s} = 0$  ( $D_s^{K^+ - K^-} \neq 0$ )

instead:  $\Delta u_V, \Delta d_V$  known from SIDIS  $\pi^\pm$  without any assumptions, then  $K^\pm$  determine  $\Delta s - \Delta \bar{s}$  - LO and NLO

## SIDIS – $\Lambda, \bar{\Lambda}$

$\Rightarrow$  SU(2):  $D_u^{\Lambda - \bar{\Lambda}} = D_d^{\Lambda - \bar{\Lambda}}$ ,  
but  $D_s^{\Lambda - \bar{\Lambda}} \neq 0 \Rightarrow \Lambda, \bar{\Lambda}$  determine  $\Delta s - \Delta \bar{s}$  without any assumptions

$\Delta s - \Delta \bar{s} = ?, SIDIS - K^\pm, \underline{\text{LO}}$

$$\underline{\underline{D_d^{K^+ - K^-} = 0 \text{ assumed}}}$$

[recall:  $K^+ = (\bar{s}u), K^- = (s\bar{u})$ ]

$$A_p^{K^+ - K^-} = \frac{4\Delta u_V D_u^{K^+ - K^-} + (\Delta s - \Delta \bar{s}) D_s^{K^+ - K^-}}{4u_V D_u^{K^+ - K^-}}$$

$$A_n^{K^+ - K^-} = \frac{4\Delta d_V D_u^{K^+ - K^-} + (\Delta s - \Delta \bar{s}) D_s^{K^+ - K^-}}{4d_V D_u^{K^+ - K^-}}$$

$$\Rightarrow (\Delta s - \Delta \bar{s}) D_s^{K^+ - K^-} = ?$$

→ note:  $D_s^{K^+ - K^-}$  is not small

⇒ inform. about  $(\Delta s - \Delta \bar{s}) \neq 0$ ?

From unpolarized SIDIS:  $\Rightarrow D_u^{K^+ - K^-}(z, Q^2)$ :

$$R_p^{K^+ - K^-} = \frac{u_V D_u^{K^+ - K^-}}{\sigma_p^{DIS}}$$

$$R_n^{K^+ - K^-} = \frac{d_V D_u^{K^+ - K^-}}{\sigma_n^{DIS}}$$

$$\underline{\Delta s - \Delta \bar{s}} = ? - SIDIS - K^\pm, \underline{NLO}$$

NLO: the same quantities enter

$$A_p^{K^+ - K^-} = \frac{[\Delta u_V D_u + (\Delta s - \Delta \bar{s}) D_s] \otimes (1 + (\alpha_s) \Delta C_{qq} \otimes)}{u_V \otimes (1 + (\alpha_s) C_{qq} \otimes) D_u^{K^+ - K^-}}$$

$$A_n^{K^+ - K^-} = \frac{[\Delta d_V D_u + (\Delta s - \Delta \bar{s}) D_s] \otimes (1 + (\alpha_s) \Delta C_{qq} \otimes)}{d_V \otimes (1 + (\alpha_s) C_{qq} \otimes) D_u^{K^+ - K^-}}$$

$\Rightarrow$  2 eqs. for  $(\Delta s - \Delta \bar{s}) \otimes (1 + (\alpha_s) \Delta C_{qq} \otimes) D_s^{K^+ - K^-}$ .

$\Rightarrow$  inform about  $(\Delta s - \Delta \bar{s}) \neq 0?$

From unpolarized SIDIS:  $\Rightarrow D_u^{K^+ - K^-}(z, Q^2)$ :

$$R_p^{K^+ - K^-} = \frac{2 u_V [1 + \otimes(\alpha_s/2\pi) C_{qq} \otimes] D_u^{K^+ - K^-}}{9 F_1^p [1 + 2\gamma(y) R^p]}$$

$$R_n^{K^+ - K^-} = \frac{d_V [1 + \otimes(\alpha_s/2\pi) C_{qq} \otimes] D_u^{K^+ - K^-}}{18 F_1^n [1 + 2\gamma(y) R^n]}.$$

$$\underline{s - \bar{s}} = ?$$

LO:

$$R_p^{K^+ - K^-} = \frac{4 u_V D_u^{K^+ - K^-} + (s - \bar{s}) D_s^{K^+ - K^-}}{\sigma_p^{DIS}}$$

$$R_n^{K^+ - K^-} = \frac{4 d_V D_u^{K^+ - K^-} + (s - \bar{s}) D_s^{K^+ - K^-}}{\sigma_n^{DIS}}$$

NLO:

$$R_p^{K^+ - K^-} = \frac{[4 u_V D_u^{K^+ - K^-} + (s - \bar{s}) D_s^{K^+ - K^-}] (1 + \otimes \alpha_s C_{qq})}{\sigma_p^{DIS}}$$

$$R_n^{K^+ - K^-} = \frac{[4 d_V D_u^{K^+ - K^-} + (s - \bar{s}) D_s^{K^+ - K^-}] (1 + \otimes \alpha_s C_{qq})}{\sigma_n^{DIS}}$$

# Testing LO

LO:

$$\Delta\sigma_p^{h+\bar{h}} = 4\Delta\tilde{u}D_u^{h+\bar{h}} + \Delta\tilde{d}D_d^{h+\bar{h}} + \Delta\tilde{s}D_s^{h+\bar{h}}$$

$$\Delta\tilde{q} = \Delta q + \Delta\bar{q}$$

C-inv:  $D_q^{h+\bar{h}} = D_{\bar{q}}^{h+\bar{h}}$

$$\begin{aligned} \frac{\Delta\sigma_p^{h+\bar{h}} - \Delta\sigma_n^{h+\bar{h}}}{\sigma_p^{h+\bar{h}} - \sigma_n^{h+\bar{h}}} (x, \textcolor{blue}{z}, Q^2) &= \frac{\Delta\tilde{u} - \Delta\tilde{d}}{\tilde{u} - \tilde{d}} (x, Q^2) \\ &= \frac{g_1^p - g_1^n}{F_1^p - F_1^n} (x, Q^2) \end{aligned}$$

$h = \pi^\pm, K^\pm$ , etc. and their sum  $h^\pm$

## Advantages:

- $z$  is a passive observable
- no dependence on  $\Delta\bar{q}$ ,  $\Delta\bar{s}$ ,  $g$  and  $D^h$
- only measurable quantities enter

$$\Delta q_3(x, Q^2) = (\Delta u + \Delta \bar{u}) - (\Delta d + \Delta \bar{d})$$

obtained directly through:

$$g_1^p(x, Q^2) - g_1^n(x, Q^7) = \frac{1}{6} \Delta q_3|_{LO}$$

## Integrated:

$$\frac{\int dx \int dz [\Delta\sigma_p^{h+\bar{h}} - \Delta\sigma_n^{h+\bar{h}}]}{\int dx \int dz [\sigma_p^{h+\bar{h}} - \sigma_n^{h+\bar{h}}]} = \frac{g_A/g_V}{3S_G}$$

- used:

The Bjorken sum rule:

$$\begin{aligned} \int dx (g_1^p - g_1^n) &= (\Delta\tilde{u} - \Delta\tilde{d})|_{LO} = g_A/g_V \\ g_A/g_V &= 1.2670 \pm 0.0079 \end{aligned}$$

The Gottfried sum rule:

$$\begin{aligned} S_G &= \int dx \frac{F_2^p - F_2^n}{x} = e_u^2 - e_d^2 + \frac{2}{3} \int dx (\bar{u} - \bar{d}) \\ S_G &= 0.235 \pm 0.026 \end{aligned}$$

- remark

The Bjorken sum rule in NLO:

$$\begin{aligned} \int dx (g_1^p - g_1^n) &= \frac{1}{6} (\Delta\tilde{u} - \Delta\tilde{d}) \left( 1 - \frac{\alpha_s(Q^0)}{\pi} \right) \\ &= \frac{1}{6} g_A/g_V \left( 1 - \frac{\alpha_s(Q^2)}{\pi} \right) \end{aligned}$$

## Testing LO if HTs

- if no HTs in FFs:

$$\begin{aligned}\Delta\sigma_p^{h+\bar{h}} = & \ 4[\Delta\tilde{u} + \Delta H(u)]D_u + [\Delta\tilde{d} + \Delta H(d)]D_d \\ & + [\Delta\tilde{s} + \Delta H(s)]D_s^{h+\bar{h}}\end{aligned}$$

then:

$$\frac{\Delta\sigma_p^{h+\bar{h}} - \Delta\sigma_n^{h+\bar{h}}}{\sigma_p^{h+\bar{h}} - \sigma_n^{d+\bar{h}}}(x, \textcolor{blue}{z}) = \frac{\Delta q_3 + \Delta H(u) - \Delta H(d)}{q_3 + H(u) - H(d)}(x)$$

$z$  = passive observable

- if  $\Delta H(q) = \Delta H^{DIS}(q)$ :

$$\frac{\Delta\sigma_p^{h+\bar{h}} - \Delta\sigma_n^{h+\bar{h}}}{\sigma_p^{h+\bar{h}} - \sigma_n^{d+\bar{h}}}(x, \textcolor{blue}{z}, Q^2) = \frac{g_1^p - g_1^n}{F_1^p - F_1^n}(x, Q^2)$$

i.e. the same relation, but HTs included

- SU(2) inv.  $\Rightarrow$  no assumptions about  $\Delta s$

## CONCLUSIONS

We suggest a model independent approach to  
SIDIS

through the difference asymmetries

$$A^{h-\bar{h}}, R^{h-\bar{h}} \text{ and } A_{n-p}^{h+\bar{h}}$$

advantage : only measurable quantities are used

the price : precise measurements needed

- SIDIS- $\pi^\pm$ : pol. and unpol. determine:

- 1) the valence quarks:  $\Delta u_V, \Delta d_V$
- 2) SU(2) breaking for the pol. sea:  $\Delta \bar{u} - \Delta \bar{d}$
- 3)  $D_u^{\pi^+ - \pi^-}$   
→ LO & NLO  
→ no assumptions about  $\Delta q_{sea}, \Delta G$  and FFs

to be measured in JefLab –

- tests for the reliability of LO – "passive" observable

- SIDIS  $K^\pm$ :  $\Delta s - \Delta \bar{s} \neq 0?$
- HTs treated if  $\Delta H^{\pi^+ - \pi^-} \rightarrow \Delta H^{DIS}$   
⇒ no HTs in FFs ???